On The Recently Discovered Pulsations From RX J1856.5-3754

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Abstract

An explanation of the recently discovered 7 s pulsations from the isolated neutron star RX J1856.5-3754 is presented. It is assumed that the real spin period of this source is ≈ 1 s, whereas the observed spin-modulation is caused by the presence of a nearly transverse, very low frequency drift waves in the pulsar magnetosphere. It is supposed that the period of the drift wave is equal to a recently observed one. The simulated lightcurve is plotted, the angular parameters are defined and the value of the pulsed fraction of only $\sim 1.2\%$ is explained.

Key words: (stars:) pulsars: individual RX J1856.5-3754, stars: magnetic fields, radiation mechanisms: non-thermal
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1 Introduction

None of the previous analysis of the X-ray data of RX J1856.5-3754 (henceforward RXJ1856) revealed any significant periodicity (Pons et al. , 2002; Ransom et al. , 2002; Drake et al. , 2002; Burwitz et al. , 2003). On the contrary a recent XMM-Newton observation of RXJ1856 has discovered that this isolated neutron star pulsates with a period of 7.055 s (Tiengo & Mereghetti , 2007).

This object has a completely featureless X-ray and optical spectra. The lack of any significant spectral features in the X-ray spectrum argues against a heavy element atmosphere (Burwitz et al. , 2001, 2003), whereas single temperature hydrogen atmosphere fits over-predict the optical flux by a large

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factor (Pavlov et al. , 1996; Pons et al. , 2002; Burwitz et al. , 2003). As the soft X-ray spectrum is well fitted by the Planckian spectrum with a temperature 63 ± 3eV (Burwitz et al. , 2003). It has been proposed that the star has no atmosphere, but a condensed matter surface (Burwitz et al. , 2001; Turolla, Zane & Drake , 2004). Such a surface might emit a featureless, likely a blackbody spectrum, at a temperature close to that of the surface, as suggested by Pavlov (2000). The overall spectra of this source has often been described by a two-temperature blackbody models (Pons et al. , 2002; Pavlov, Zavlin & Sanwal , 2002; Burwitz et al. , 2003), because the parameters derived from X-rays do not fit the optical data, which shows the Rayleigh-Jeans slope with an intensity a factor of 6 larger than that of a X-ray emission. Alternatively a recent paper by Ho et al. (2007) explains the observed featureless spectra of this object assuming that the star has a thin magnetic, partially ionized hydrogen atmosphere on top of a condensed surface. Though, one of important uncertainties for this model appears to be a creation of thin hydrogen atmospheres. However, to make these models work, the NS has to have a condensed matter surface, which requires the specific conditions (Lai & Salpeter , 1997; Lai , 2001). Also, it remains to be seen weather a detailed analysis of magnetically condensed matter confirms the required non-uniform distribution of the surface temperature (two-component blackbody model). So we must conclude that existing models, based on an assumption that the emission of RXJ1856 has a thermal nature face numerous problems.

In the present paper we propose our explanation of the detected pulsations in the X-ray emission of RXJ1856, which is naturally possible based on emission model developed by Chkheidze & Machabeli (2007). In this paper it is assumed that the emission of this object is generated by the synchrotron radiation, which is created as the result of appearance of pitch angles during the quasi-linear stage of the cyclotron instability. We suppose that the model proposed by Chkheidze & Machabeli (2007) works, which assumes the case of a nearly aligned rotator, whereas the periodic variations of the observed emission may be caused by the presence of a very low frequency, nearly transverse drift waves in the pulsar magnetosphere. These waves propagate across the magnetic field and encircle the open field line region of the pulsar magnetosphere (Kazbegi et al. , 1991, 1996). They are not directly observable but only cause the periodic change of the direction of the pulsar emission (Lomiashvili, Machabeli & Malov , 2006).

In this paper, we give a description of the emission mechanism in Section 2. The mechanism of change of the pulsar radiation direction is described in Section 3, our model is presented in Section 4 and conclusions are done in Section 5.

2 Emission mechanism

As it is known the pulsar magnetosphere is filled by a dense relativistic electron-positron plasma. The (e^+e^-) pairs are generated as a consequence of the avalanche process (first described by Sturrock (1971)) and flow along the open magnetic field lines. The plasma is multi-component, with a one-dimensional distribution function (see Fig.1 from Arons (1981)) and consists of the following components: the bulk of plasma with an average Lorentz-factor $\gamma_p \simeq 10$; a tail on the distribution function with $\gamma_t \simeq 10^4$ and the primary beam with $\gamma_b \simeq 10^6$. The main mechanism of wave generation in plasmas of the pulsar magnetosphere is the cyclotron instability. Generation of waves is possible if the condition of the cyclotron resonance if fulfilled (Kazbegi et al. , 1991):

$$\omega - k_\varphi V_\varphi - k_x u_x + \frac{\omega_B}{\gamma_r} = 0, \tag{1}$$

where V_φ is the particle velocity along the magnetic field, γ_r is the Lorentz-factor for the resonant particles and $u_x = cV_\varphi\gamma_r/\rho\omega_B$ is the drift velocity of the particles due to curvature of the field lines (ρ is the radius of curvature of the field lines and $\omega_B = eB/mc$ is the cyclotron frequency). Here cylindrical coordinate system is chosen, with the x-axis directed transversely to the plane of field line, when r and φ are the radial and azimuthal coordinates. During the quasi-linear stage of the instability a diffusion of particles arises as along, also across the magnetic field lines. Therefore, plasma particles acquire transverse momenta and begin to rotate along the Larmor orbits. The synchrotron emission is generated as a result of the appearance of pitch angles.

In Chkheidze & Machabeli (2007) it has been assumed that the emission of RXJ1856 is generated by the synchrotron mechanism, which is created as the result of the cyclotron instability. Though, the original waves excited during the cyclotron resonance come in the radio domain, the radio emission is not observed from RXJ1856. This waves as well as the X-ray and optical emission propagate along the local magnetic field lines. One of the possible explanations why the radio emission is not detected from this object is that it is generated at lower altitudes in contrast to the X-ray and optical emission and might miss our line of sight. Another explanation is that the radio emission covers a large distance in the pulsar magnetosphere (since the model of the aligned rotator is used). So there is a high probability for it, to come in the cyclotron damping range $\omega - k_\varphi V_\varphi - k_x u_x - \omega_B/\gamma_r = 0$ (Khechinashvili & Melikidze , 1997). In this case the radio emission will not reach an observer.

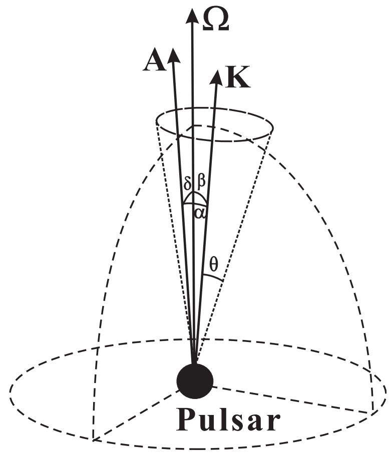

Fig. 1. Geometry of Ω - rotation, $\mathbf{K}$ - emission and $\mathbf{A}$ - observers axes. Angles δ and ϑ are constants, while β and α are oscillating with time.

3 Change of the field line curvature and the emission direction by the drift waves

Considered distribution function should generate various wave-modes in certain conditions. Particularly it has been shown (Kazbegi et al. , 1991, 1996) that a very low frequency, nearly transverse drift waves can be excited. They propagate across the magnetic field, so that the angle between $\mathbf{k}$ and $\mathbf{B}$ is close to $\pi/2$. In other words, $k_\perp/k_\varphi \gg 1$, where $k_\perp = (k_r^2 + k_\varphi^2)^{1/2}$. The period of the drift waves P_{dr} can be written as (Lomiashvili, Machabeli & Malov , 2006):

$$P_{dr} = \frac{e}{4\pi^2 mc}\frac{BP^2}{\gamma}, \tag{2}$$

where P is the pulsar spin period, γ is the Lorentz-factor of the relativistic particles and $B = B_s(R_0/R)^3$ is the magnetic field in the wave excitement region (B_s is the magnetic field at the pulsar surface and R_0 is the radius of the neutron star). It appears that the period of the drift waves can vary in a broad range.

The magnetic field of drift wave adds with the pulsar magnetic field as r component and causes changing of the curvature of field line. Even a small change of B_r causes significant change of ρ. Variation of the field line curvature can be estimated as:

$$\frac{\Delta\rho}{\rho} \approx k_\varphi r \frac{\Delta B_r}{B_\varphi}, \tag{3}$$

here k_φ is a longitudinal component of wave vector and r is distance to the center of the pulsar. It follows that even the drift wave with a modest amplitude $B_r \sim \Delta B_r \sim 0.01 B_\varphi$ alters the field line curvature substantially $\Delta\rho/\rho \sim 0.1$.

Since the pulsar emission propagates along the local magnetic field lines, curvature variation causes change of the emission direction, with the period of the drift waves.

4 The model

There is unequivocal correspondence between the observable intensity and α (the angle between the line of sight of an observer and the emission direction, see Fig. 1). Maximum of intensity corresponds to the minimum of α. The period of pulsar is the time interval between neighboring maxima of observable intensity i.e. minima of α. According to this fact, we can say that the observable period depends on time behavior of α and as it appears below it might differ from the 'real' spin period of the pulsar.

From pulsar geometry it follows that α can be expressed as (Lomiashvili, Machabeli & Malov , 2006):

$$\begin{aligned}\alpha = \arccos[&\sin\delta\sin(\beta_0 + \Delta\beta\sin(\omega_{dr}t + \varphi))\cos\Omega t \\ &+ \cos\delta\cos(\beta_0 + \Delta\beta\sin(\omega_{dr}t + \varphi))],\end{aligned} \tag{4}$$

where $\Omega = 2\pi/P$ is the angular velocity of the pulsar, δ is the angle between the rotation and the observer's axes, β is the angle between the rotation and emission axes (see Fig. 1) and $\Delta\beta$ is the amplitude of changing of β.

In the absence of the drift wave $\beta = \beta_0 = const$ and consequently the period of α equals to $2\pi/\Omega$. On the other hand, if the angle between the rotation and emission axes is too small i.e. $\delta << 1$, then the period of α equals to $P_{dr} = 2\pi/\omega_{dr}$. In this case the observable period P_{obs} does not represent the real spin period of the pulsar, but equals to the period of the drift wave, which we suppose to be 7.055 s. When the real spin period of this object has been estimated by Chkheidze & Machabeli (2007) to be $P \approx 1s$.

Hence, for some values of parameters β, $\Delta\beta$, δ, φ and ϑ it is possible to explain the 7 s pulsations of RXJ1856. If we consider this object in the framework of our model its angular parameters will get the values shown in Table 1. Simulated lightcurve for RXJ1856 is presented on Fig. 2, which well expresses the value of the pulsed fraction of only $\sim 1.2\%$ (the smallest ever seen in the isolated X-ray pulsars), obtained from observations (Tiengo & Mereghetti , 2007).

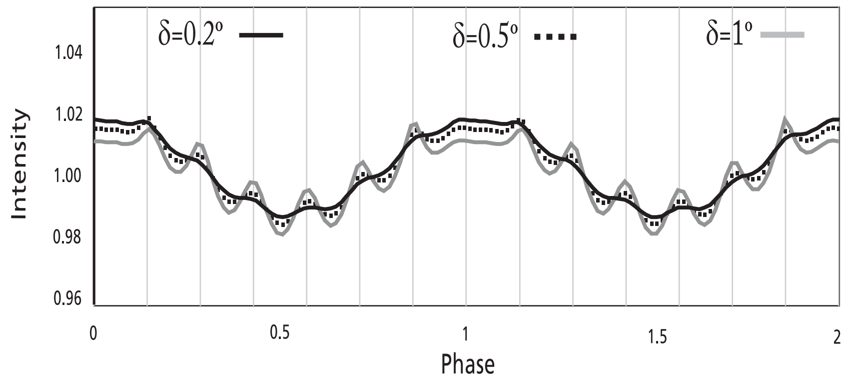

Fig. 2. Simulated lightcurve of RX J1856.5-3754

5 Conclusion

In the present paper we propose our explanation of recently discovered 7 s pulsations in the isolated neutron star RXJ1856, based on model drawn by Lomiashvili, Machabeli & Malov (2006). The main feature of this work is that the spin period of pulsar might differ from the observable one, which is the consequence of existence of very low frequency drift waves in the region of excitement of the pulsar emission. These particular waves are not detected but only result in a periodical change of curvature of the magnetic field lines, which in turn cause the change of observed radiation with a period of the drift wave.

Drift wave driven model is very convenient, since it makes able to explain almost every feature of known extraordinary pulsars such as: extremely long period radio pulsars (Lomiashvili, Machabeli & Malov , 2006), Rotation Radio Transients (Lomiashvili et al. , 2007), Anomalous X-ray Pulsars and Soft Gamma-ray Repeaters (Malov & Machabeli , 2007).

We suppose that treatment of the 'real' period of RXJ1856 can be achieved by more detailed observations. In the case of nonzero δ, which is most likely, variations with different time-scale should be appeared with value of the pulsar spin period, see Fig. 2. If this is confirmed, it will benefit to our model.

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Table 1
The values for parameters of RX J1856.5-3754

$P_{obs}(s)$	$P(s)$	$\Delta\beta$	β_0	δ	ϑ
7.055	≈ 1	0.02	0.02	0.01	0.03

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